

Design of an Electron Beam Dump at SLAC

Early in 1964 Mr. Dieter R. Walz, a member of the technical staff at SLAC (Stanford Linear Accelerator) was put in charge of developing a "beam dump". This device is a heat exchanger capable of absorbing and dissipating the high energy electron beams which must be disposed of at the end of the 2-mile long linear accelerator (linac). The electron beams are pulsed, having a rate of up to 360 pulses per second. The pulse width is approximately 1.7 microseconds. Since the accelerator is expected to operate on a 24 hour a day schedule, it is important that the beam dump be capable of continuously absorbing and dissipating the full beam power for an extended period.

Dieter, a German by birth, studied mechanical engineering and majored in Strength of Materials at the Technical University of Stuttgart, where he received the B.S. degree in 1958 and the M. S. degree in 1960. He came to Stanford University and pursued graduate study in the thermo sciences and obtained an M. S. degree in 1962 and the professional degree of Engineer in 1964 with emphasis on Heat Transfer and Nuclear Reactor Technology. During 1963 he joined SLAC, first on a part time basis while pursuing his research program at Stanford University. He later switched to full time and is currently in charge of development, performance and maintenance of high-power beam absorbers such as beam dumps of various types, energy slits and collimators, windows and targets. In addition he is in charge of research projects in the fields of radiation chemistry, radiation effects on materials and related solid state physics problems, electromagnetic cascade shower development, and electron beam optics. He has had anywhere from 5 to 15 engineers and designers working under him.

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This case was prepared by Professor Munir R. El-Saden, California State College at Fullerton, during the 1967 Summer Institute on Case Methods supported by the National Science Foundation at Stanford University.

Theory

When a pulse of high energy electrons strikes a target, the fast electrons interact with the nuclei of the target atoms. This interaction results in radiation and collision processes, i.e., the emission of photons and other subatomic particles. These secondary particles in turn participate in interactions with other nuclei of the host target. The result is a shower effect of radiation whose rate increases with the distance from the plane of entrance of the electrons (face of the target). The phenomenon is called development of the electromagnetic cascade shower and it reaches a maximum at some point in the target which is called the "shower maximum." Beyond the shower maximum the shower is exponentially attenuated, as the particle population decreases due to absorption processes. Exhibit 1 shows shower curves for three different materials based on radiation length as linear dimension, where "one radiation length" is defined as the distance of matter traversed in which an electron's energy is reduced by radiation to $1/e$ of its original value. Exhibits 2a and 2b show the same shower curves based on centimeters as linear dimension; Exhibit 3 gives the radial shower development at the shower maximum.

The phenomenon of shower development is accompanied by power deposition, heat generation and a temperature rise. The resulting temperature profile in the target is proportional to the curve of Exhibits 2.

If repeated pulses are imparted to the target, the temperature profile will be raised until melting (or vaporization) of the material commences at the shower maximum and then progresses throughout the target material.

The radiation length and the temperature rise per pulse at the shower maximum are material properties that must be considered in the design of a beam dump. Such information is presented in Table 1 for a number of materials.

TABLE 1

<u>Material of Target</u>	<u>Maximum temperature rise per pulse; C</u>	<u>Radiation length, cm.</u>
Water	1	37.2
Aluminum	18	9.0
Copper	160	1.44
Tungsten	1000	0.35

This data was determined theoretically for an electron beam having the following properties:

Pulse rate=360 pulses per second

Pulse width=1.7 microseconds

Average energy per

electron in the beam ⁽¹⁾=20 GeV⁽²⁾

Average power of the beam=2.2 MW⁽³⁾

Incident beam diameter=0.5 cm.

These properties were chosen because of the general design requirements that the beam dump be capable of dissipating electron beams of 2.2 MW average power with electron energies in the range of 11 to 25 GeV. The beams are from 0.2 to 0.6 cm. in diameter.

Design

Dieter studied Exhibit 1 and decided that a total of 30 radiation lengths of equivalent material was needed to absorb and fully attenuate the beam. "Water is a convenient medium for the beam dump," remarked Dieter, "because its maximum temperature rise per pulse is 1°C which is

(1) The beam is assumed to be rectified and the electron energies fall in a narrow range.

(2) GeV=Giga electron volt= 10^9 eV

(3) MW=mega watt= 10^6 watt

quite tolerable, but its radiation length of 37.2 cm. is too long, to practically provide for 30 radiation lengths. On the other hand, the radiation length in copper is only 1.44 cm. but copper suffers from a high temperature rise per pulse. An optimum design can be achieved by using a composite of these two materials." He finally decided that 10 radiation lengths of water plus 20 radiation lengths of copper would be an appropriate medium for the dump. "In this manner," Dieter pointed out, "the high energy electron beam would be attenuated considerably before entering the copper and hence the temperature rise in the latter will not be excessive."

Dieter was now satisfied with the above plan for handling one pulse of radiation. On the other hand, a pulsing beam of 360 pulses per second will cause the local temperature rise to grow rather fast and thus produce overheating and material failure. To overcome this problem, Dieter decided that the water must be convected or circulated while the copper is water cooled.

Exhibit 4 shows a schematic diagram of Dieter's conceptual design. The temperature rise of the water across the dump must be held at some reasonable value.

Dieter explained that due to the high level of induced radioactivity the dump would be inaccessible after a relatively short time. Therefore, conservative design values must be used to insure maximum useful life and minimize maintenance. Also, because of the radioactivity in the water, a two-loop system is needed, as shown in Exhibit 5. However, Dieter's current concern is with the beam dump and the primary, radioactive water loop.

The final beam dump design that Dieter came up with is shown in Exhibit 6. It is designed to dissipate an average power of 2.2 MW for the range of 11 to 25 GeV from an incident electron beam which may vary in diameter from 0.2 to 1.0 cm. The water flow is 550 gpm at a pressure

of 25 psig and the inlet temperature is $\leq 100^{\circ}\text{F}$. The unit consists of a 55-inch diameter by 14 ft. 9-inch long stainless steel shell (not including dished heads) mounted on a mobile frame. The front section is 12 ft. 6 inches long (10 radiation lengths of water) and contains headers designed to induce vortex flow of the water. The rear section contains 19 hard chrome-plated, water cooled, copper plates of graduated thickness to provide 20 radiation lengths of material. Cooling water enters the rear section and flows into the front section through a tangential header which imparts a swirling motion and is discharged through a central pipe. The inlet window for the beam consists of a 0.125-cm. (0.050-inch) thick, hemispherically shaped hard chrome-plated sheet of copper. The window can be replaced remotely. Jets insure a high water velocity at the window. Provision is made for continuous venting of gases produced by radiolytic decomposition of the water (for example H_2), for remote draining and removal of the entire dump. Exhibit 7 shows a front view of an as-built dump prior to installation.

Maintenance

For maintenance purposes, access to the radioactive primary loop system had to be planned in advance. While the system may be dismantled remotely after shut down, the difficulty lies with the radioactive isotopes which are produced in the water as a result of radiolysis and radioactive processes.

The primary isotopes that are produced in appreciable amounts are ^{15}O , ^{13}N , ^7Be , ^{11}C , and ^3H . The half-life⁽⁴⁾ of the first two isotopes is about two minutes and 10 minutes respectively, while the half-life of ^{11}C is 20.5 minutes. The elimination of these isotopes is simply

(4) Half-life is the time taken for half of the nuclei in a radioactive element to disintegrate. The number remaining in a given sample falls off exponentially with time, $N=N_0e^{-\lambda t}$ where λ is the radioactive decay constant.

accomplished by providing a few hours of waiting after shut down before starting maintenance work. On the other hand, Be^7 has a half-life of 53 days. Fortunately, the resin bed of the ion exchanger has affinity to the chemical compound(s) in which this isotope occurs and thus its detrimental effects are for the most part eliminated.

The last primary isotope which requires consideration is Tritium, H^3 . This isotope is produced at a very small rate but has a very long half-life. Thus, it accumulates in the water and in time assumes dangerous concentration.

One way of circumventing the H^3 problem is to haul the radioactive water periodically to some remote place where it can be buried. The estimated cost of this operation turned out to be high, \$6,000 every six months; dumping the system's 3000 gallons of water at \$2 per gallon. This plan was finally rejected in favor of one with considerably lower cost. This plan is based on the maximum permissible content, mpc, of H^3 in water which may be dumped in the city sewer as specified by the local code. According to this plan, the concentration of H^3 (as well as other possible isotopes) is monitored, and when it reaches one-third of mpc, the system's water is drained and dumped into the city sewer, and the system is charged with fresh water. The cost of this plan is quite reasonable and the concentration of H^3 in the sewer is not materially affected since small amounts of H^3 are always present in the sewer water from various sources.

The shut down procedure has thus been reduced to that of shutting down the system and providing enough time (a few hours) for the decay of the predominant isotopes.

The secondary radiation released as a result of the isotope decay processes described earlier is not energetic enough to cause formation of new isotopes. A minimum energy of the order of 10 MeV is required to produce a new isotope. Thus, except for cumulative radiation effects on locally employed materials and for health reasons, this radiation does not create any additional problems.

So far the highest average power yet deposited and dissipated in the beam dump was 240 kW at 17.5 GeV. To date (9/20/67), after 18 months of continuous operation, no failures have occurred.

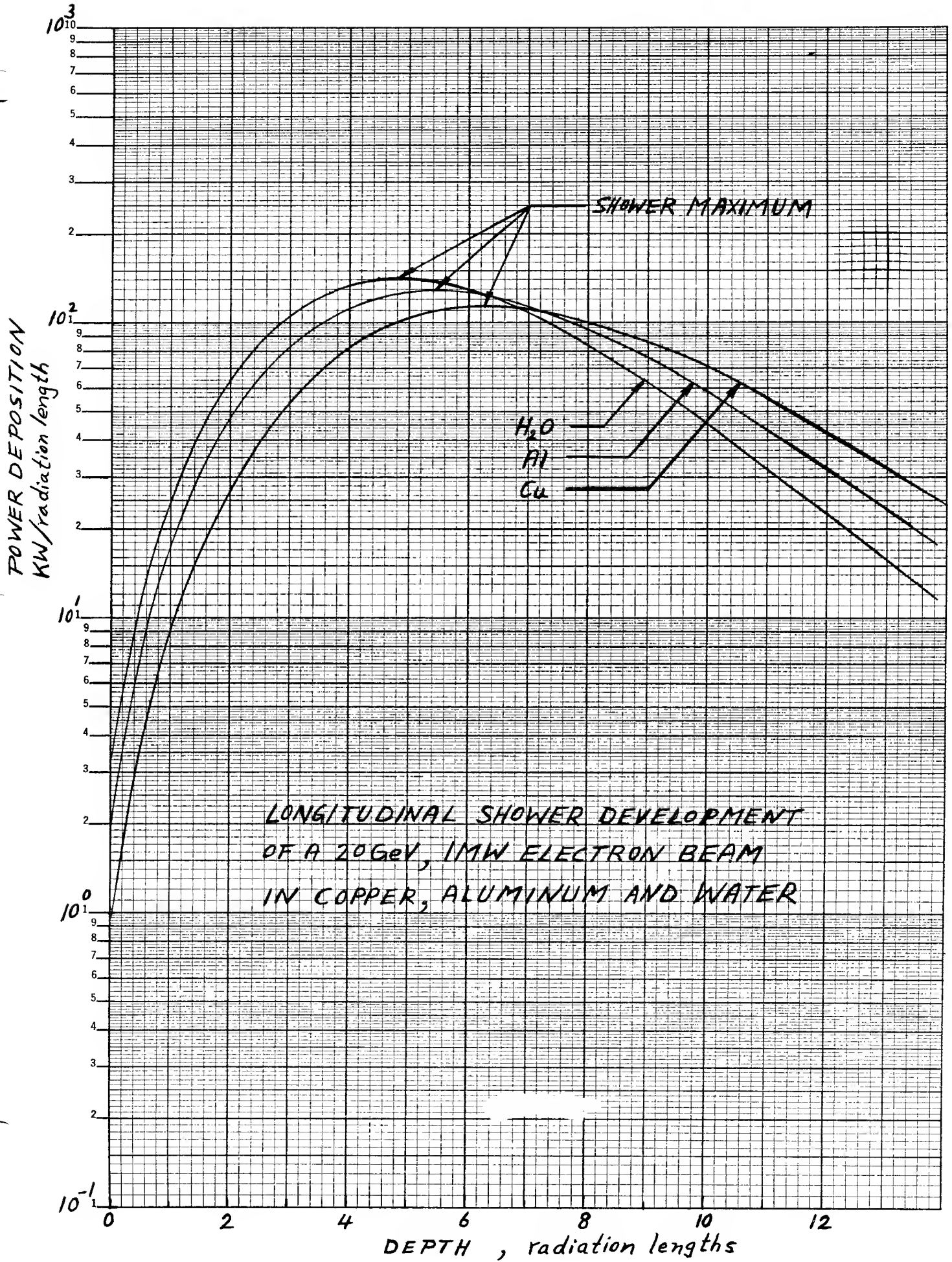
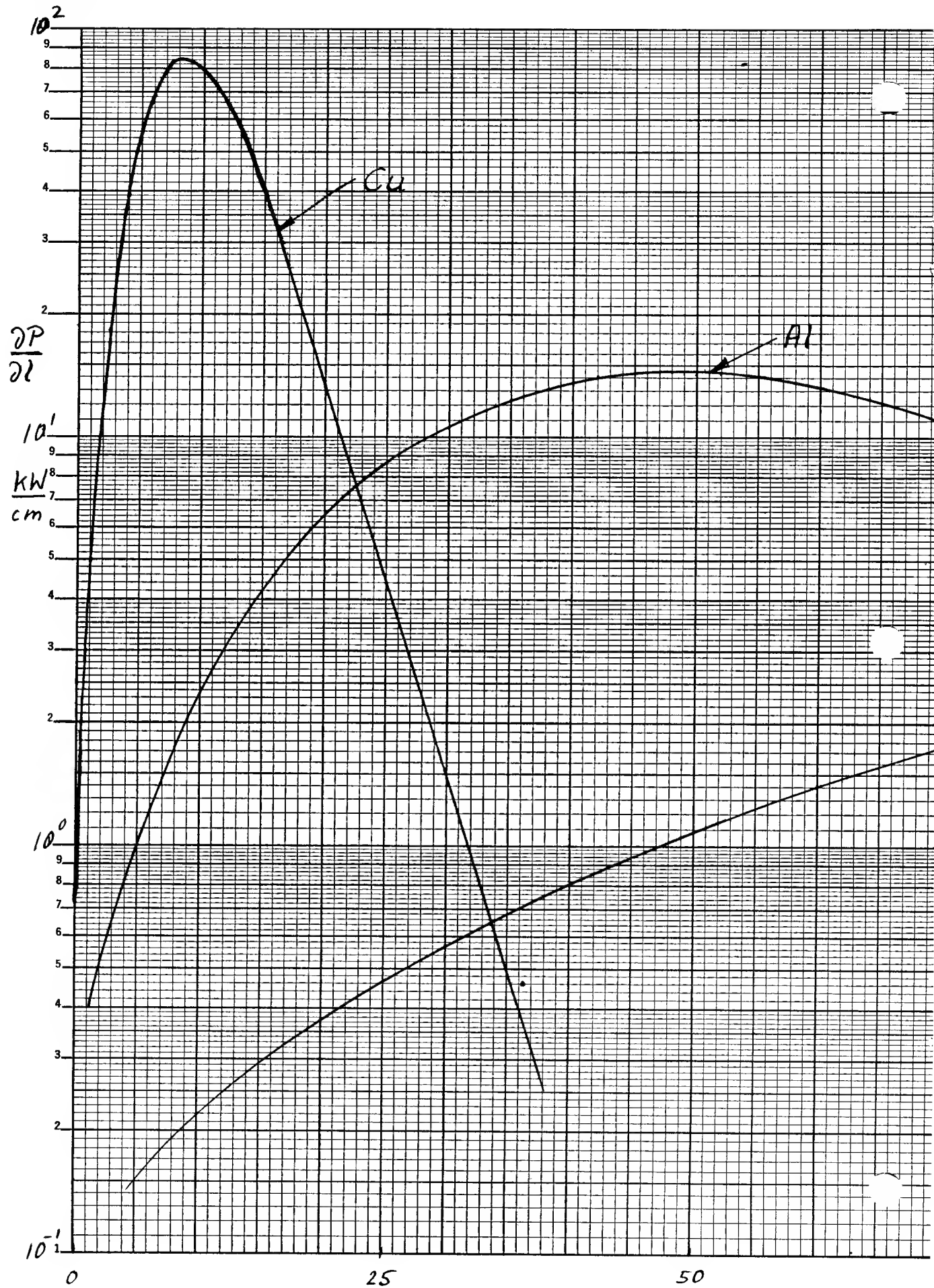
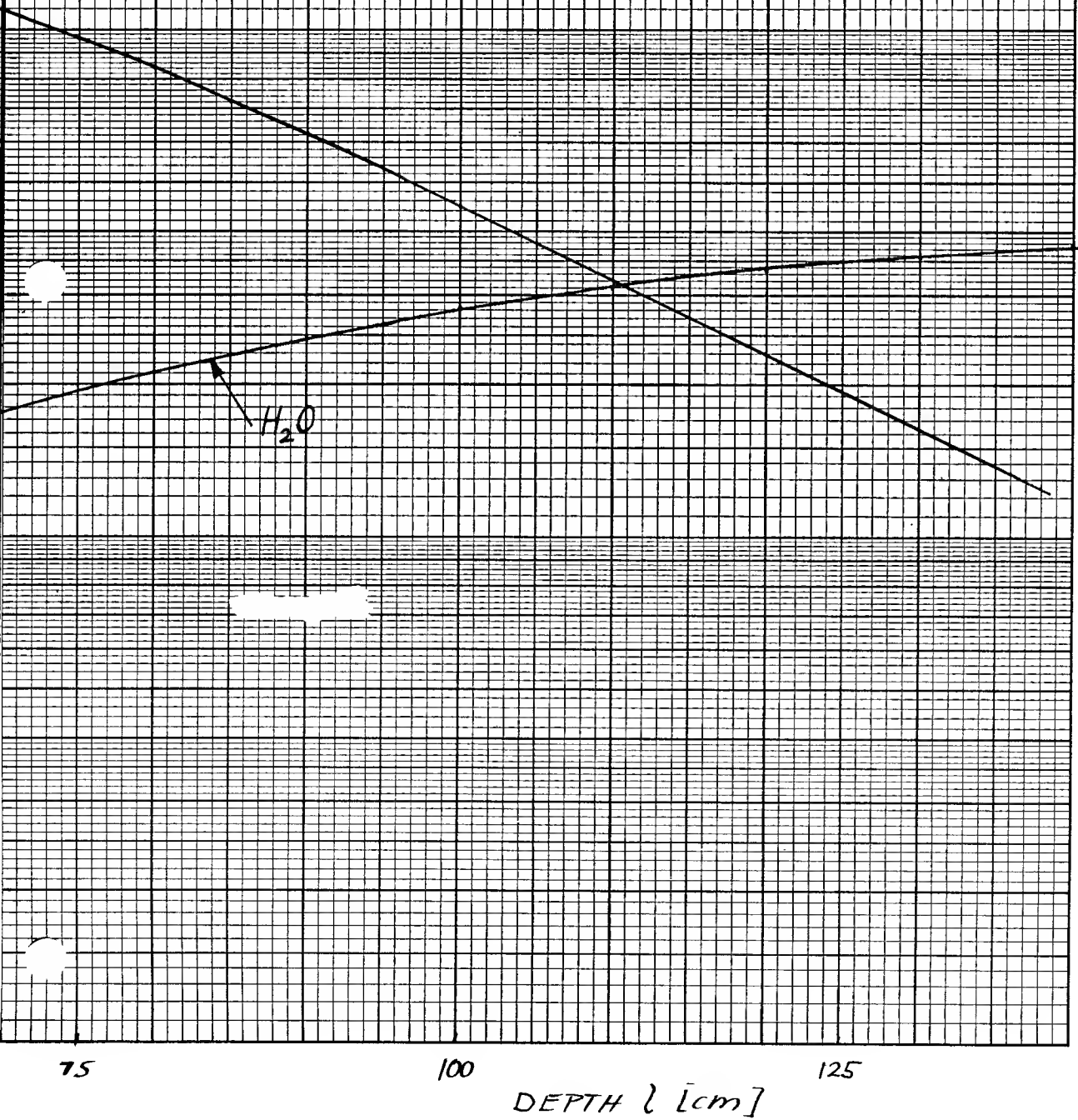
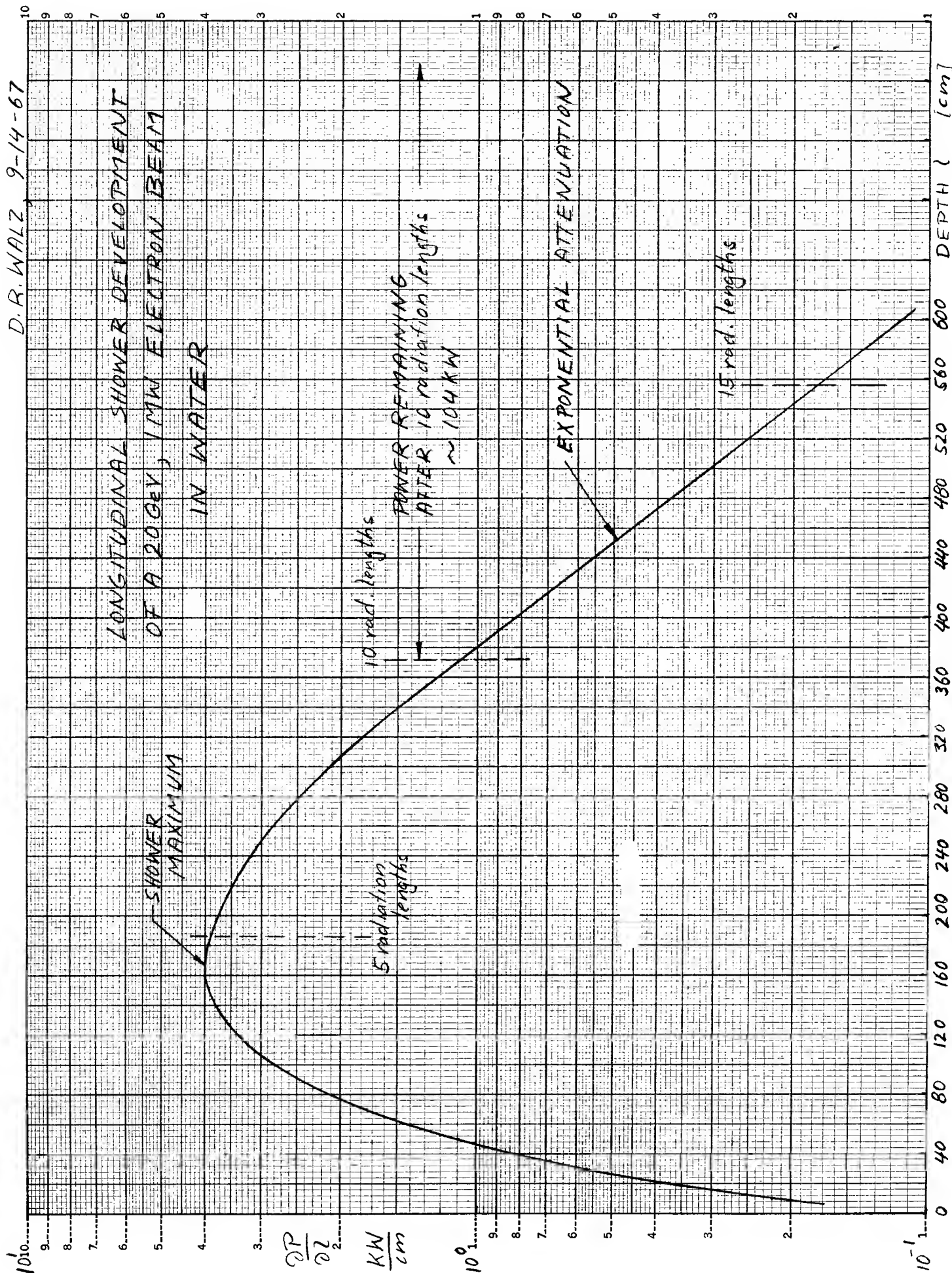


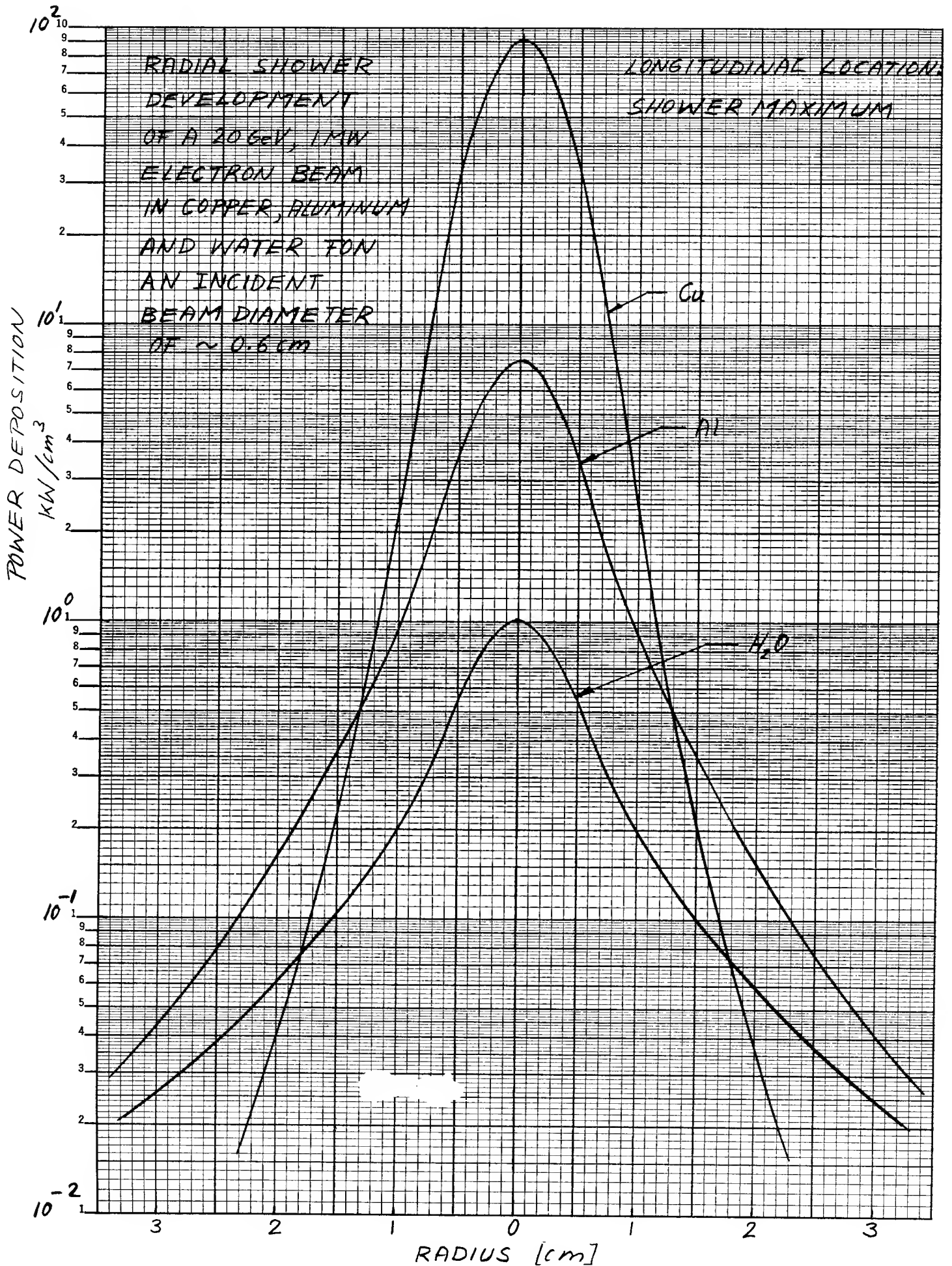
Exhibit 2a

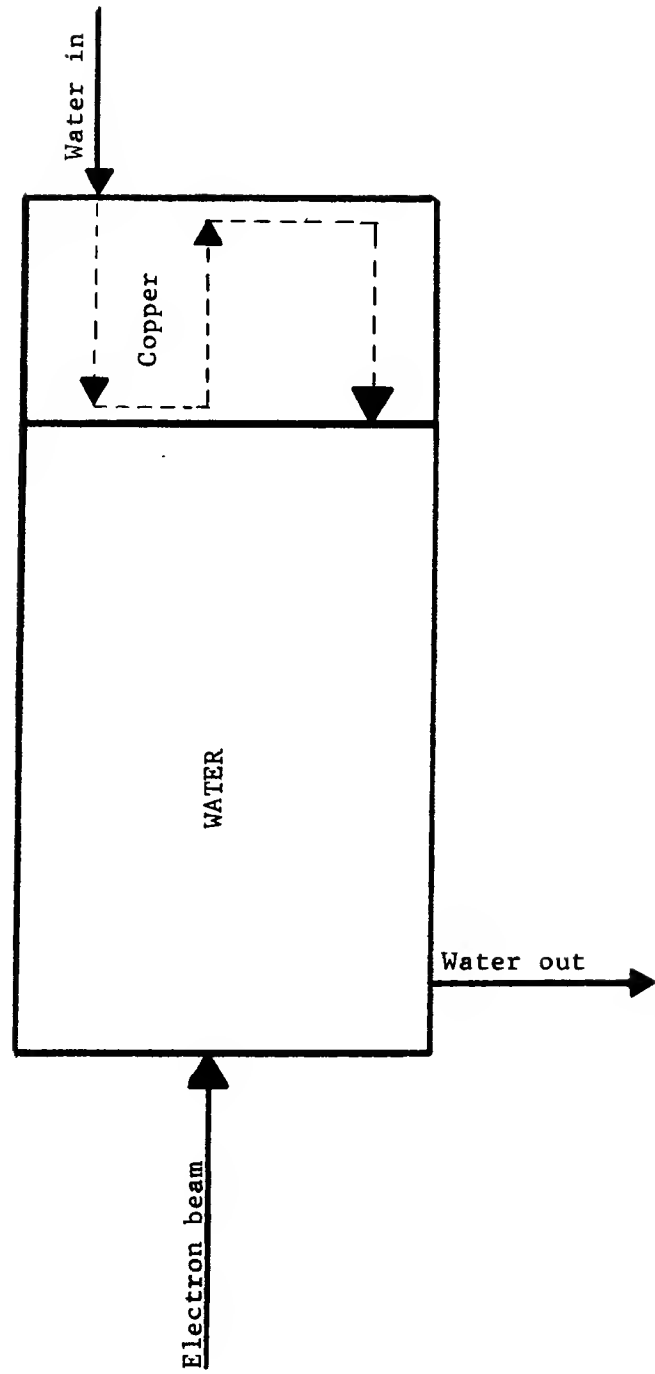


LONGITUDINAL SHOWER DEVELOPMENT
OF A 20 GeV, 1 MW ELECTRON BEAM
IN COPPER, ALUMINUM, AND WATER

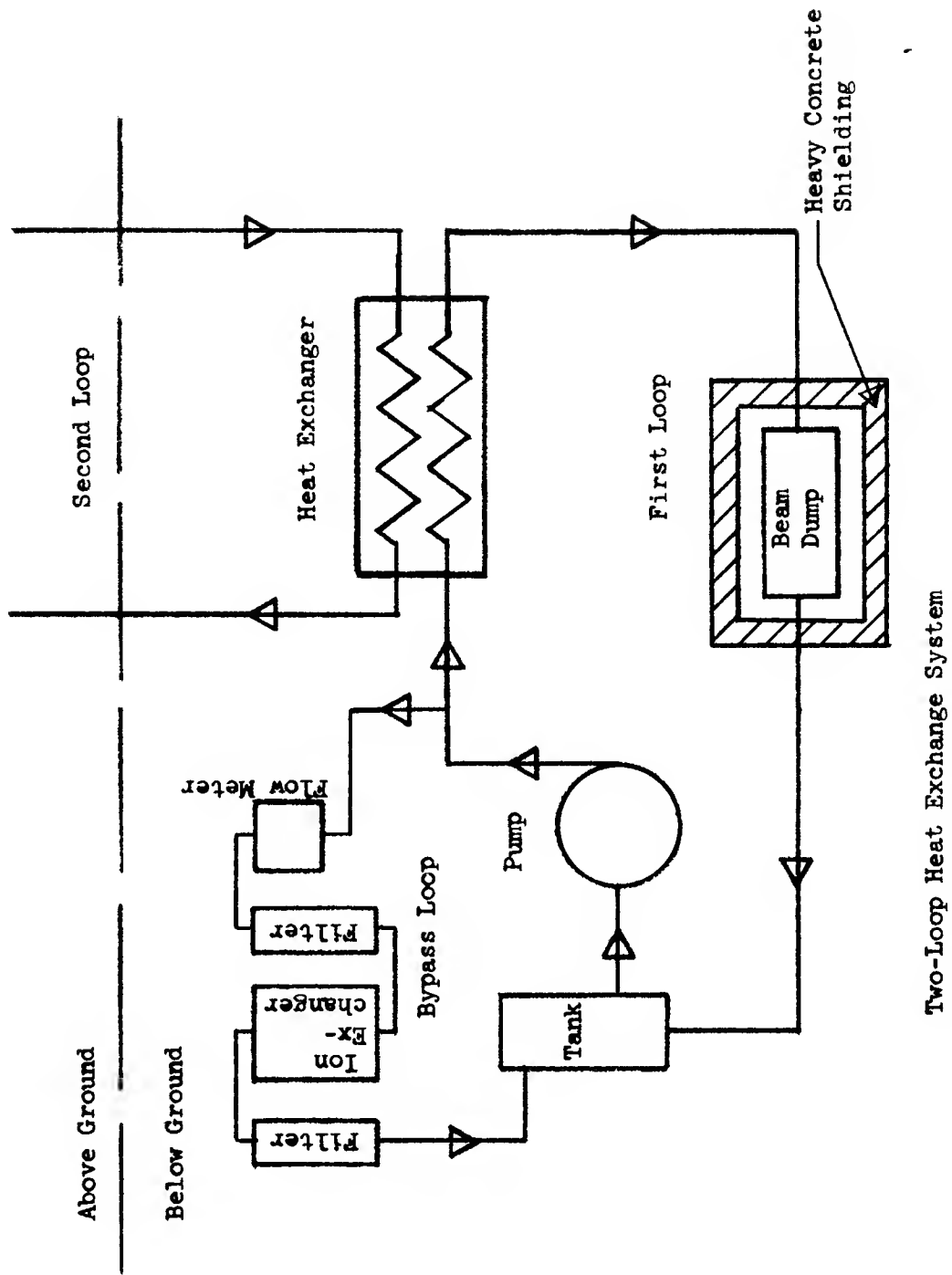


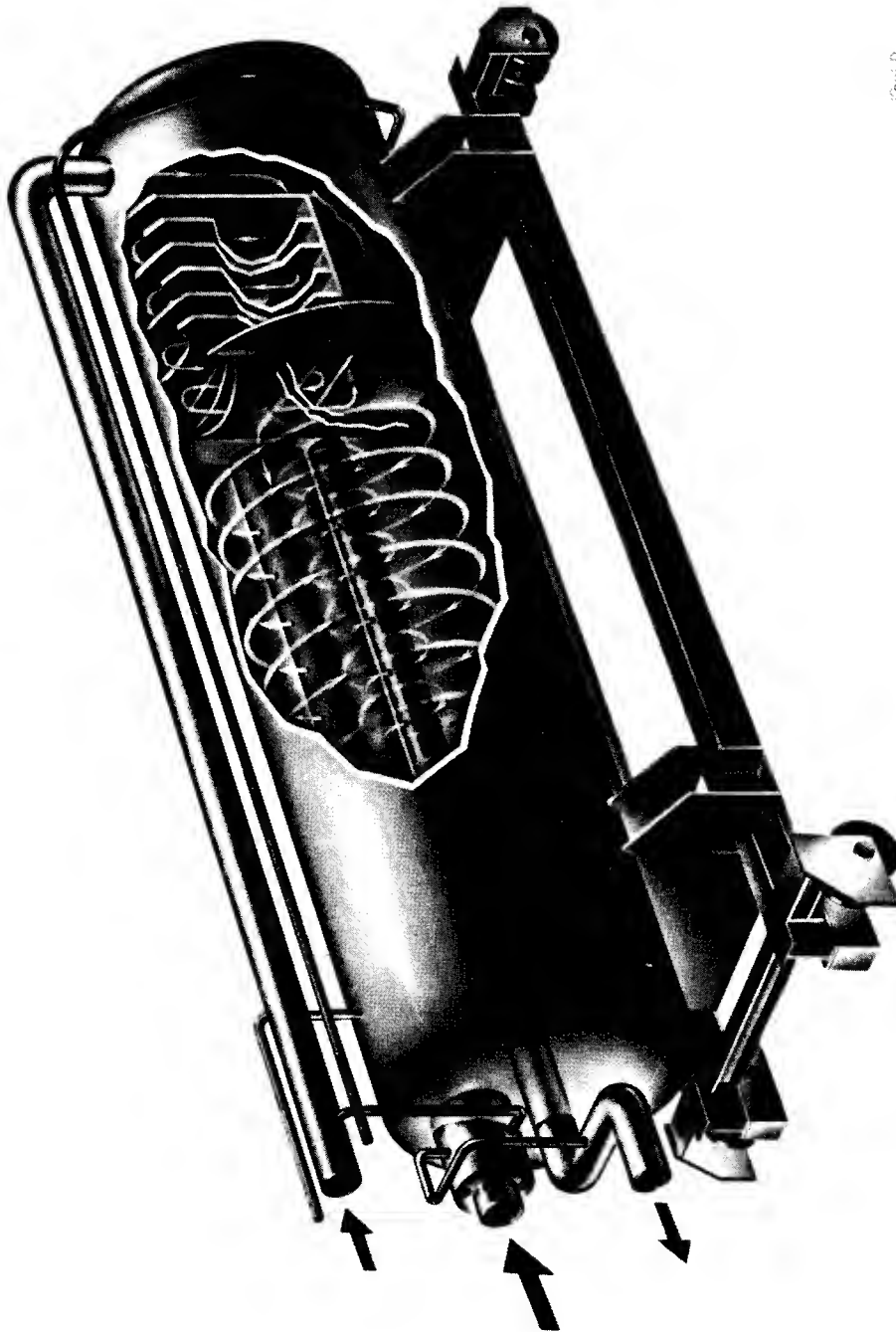




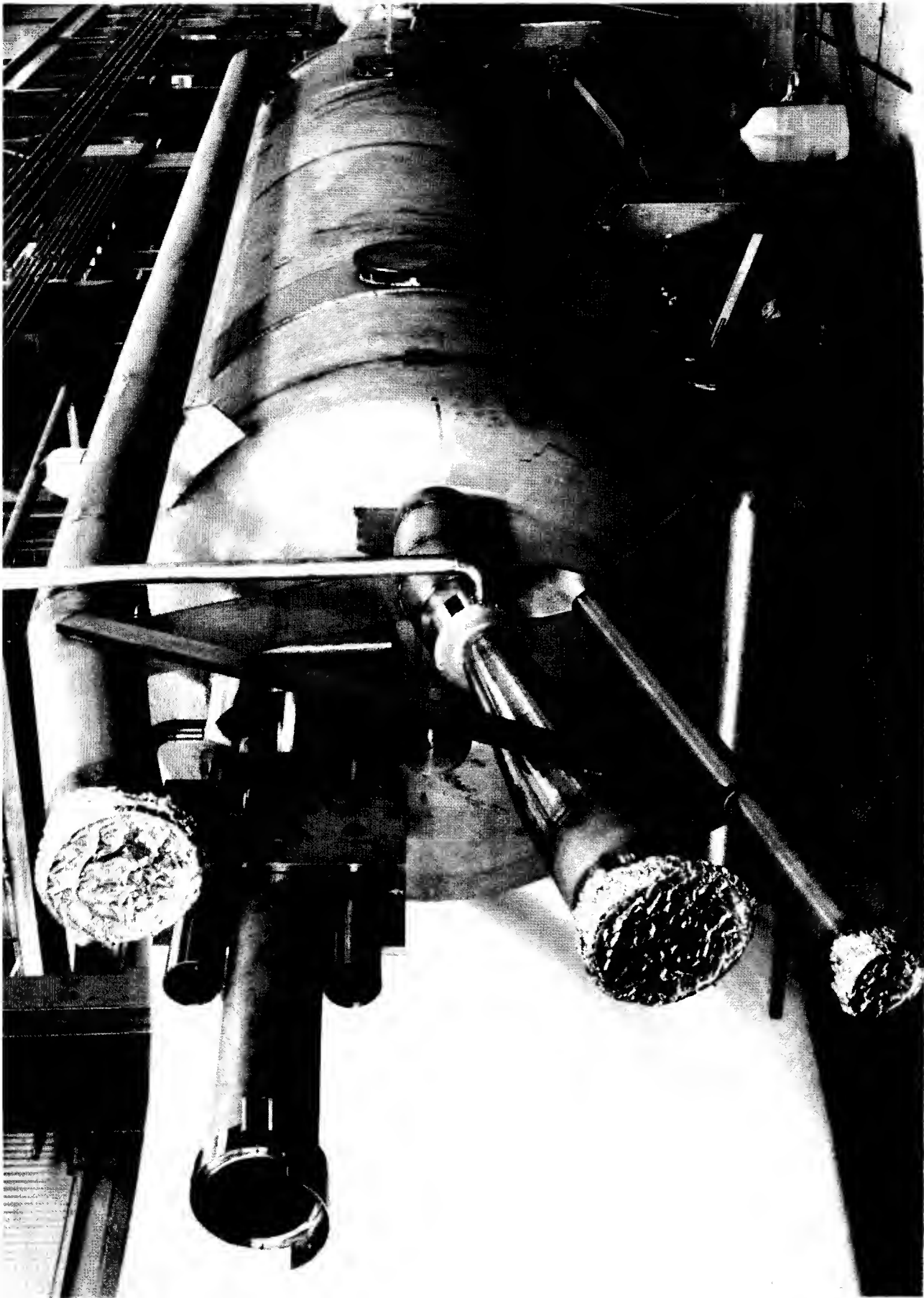


Conceptual Design of Beam Dump





Final Beam Dump Design



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Front View of an As Built Beam Dump